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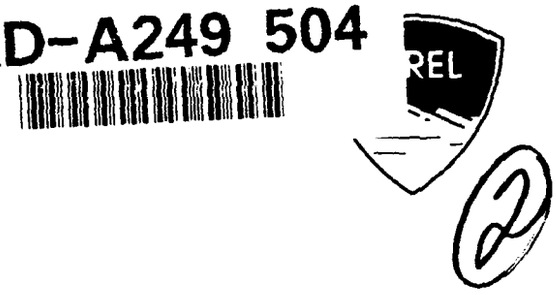

Ice Force Measurements on a Bridge Pier in the St. Regis River, New York

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Cold Regions Research & Engineering Laboratory

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Prepared for
OFFICE OF THE CHIEF OF ENGINEERS
and
NEW YORK STATE DEPARTMENT OF TRANSPORTATION

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PREFACE

This report was prepared by F. Donald Haynes, Mechanical Engineer, Dr. Devinder S. Sodhi, Research Hydraulic Engineer, Leonard J. Zabilansky, Civil Engineer, and Charles H. Clark, Electronics Technician, all of the Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by the New York State Department of Transportation and by Civil Works Project CWIS 31723, *Model Studies and Ice Effects on Structures.*

Stephen L. DenHartog and Dr. Mark Hopkins of CRREL technically reviewed the manuscript of this report. The authors are grateful to Richard Warren and Crispin Hall of the New York State Department of Transportation and to Larry Gould and Peter Stark of CRREL for their contributions to this project. The authors also thank the New York State Department of Transportation for funding this project.

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F. DONALD HAYNES, DEVINDER S. SODHI,
LEONARD J. ZABILANSKY AND CHARLES H. CLARK

INTRODUCTION

To design bridge piers that can withstand forces exerted by moving ice, it is important to develop criteria that are based on actual field measurements. Useful observations of ice–structure interaction were made by Korzhavin (1971), while ice forces have been measured by Neill (1976) and Gerard (1978) at two bridge piers in Alberta, Canada, by McFadden et al. (1981) at a bridge pier on the Yukon River and by Sodhi et al. (1983) at a bridge pier on the Ottauquechee River in Vermont. Haynes (1986) summarized many laboratory and field tests and design ice codes. The design codes that have evolved over the last 20 years have recommended that designers consider the local conditions at the time of the ice movement, for example, such as those during the annual spring breakup.

The AASHTO (1983) design code recommends using design ice pressures that correspond to the strength and condition of the ice during breakup. In 1985 engineers from the New York State Department of Transportation and CRREL met to discuss the measurement of ice forces on the new bridge to be built across the St. Regis River at Hogansburg, New York (Fig. 1). All agreed that CRREL would design an ice load panel for measuring ice forces on the upstream nose of pier 2 (the east pier).

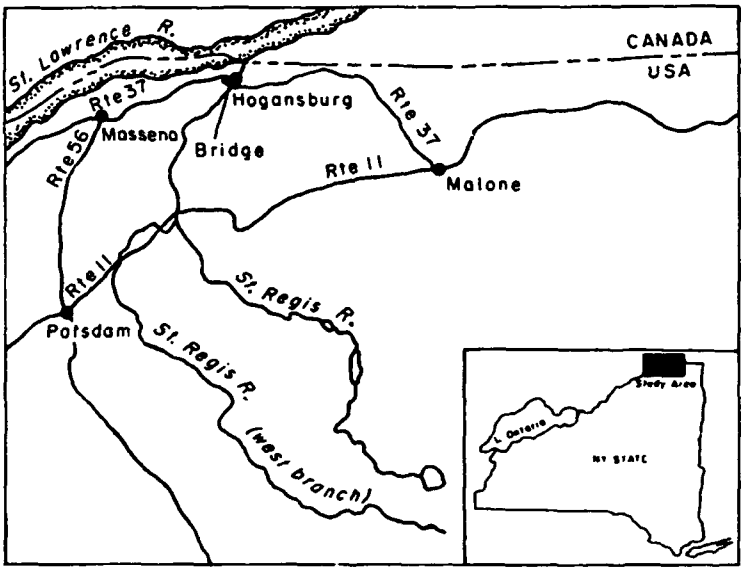

Figure 1. Location of the new bridge on the St. Regis River at Hogansburg, New York.

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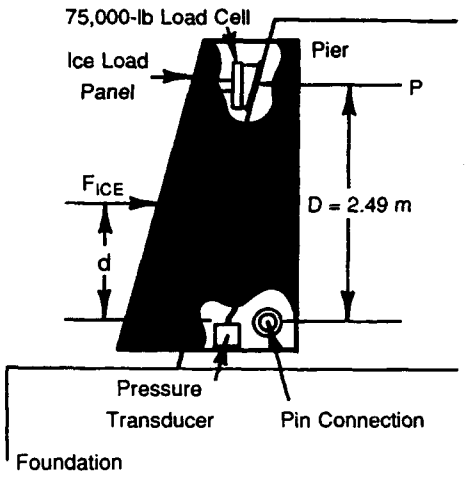


Figure 2. Ice load panel on the east pier of the new bridge.

ICE FORCE PANEL

A sketch of the ice load panel is shown in Figure 2. The panel is a simply supported beam, pinned at the bottom, having one reaction support at the top. This reaction support is a 333.6-kN (75,000-lb) load cell. The panel is a reinforced, truncated, conical steel hull made from a 1.9-cm ($^3/_4$-in.) rolled steel plate. A pressure transducer was placed inside the panel at the bottom to record the water depth above the transducer. The bridge was constructed in 1989. The ice force panel, fabricated by CBI Steel in Potsdam, New York, was installed in December 1989 by CRREL engineers and the Hugh Schickel Construction Company of Malone, New York. The 10-cm-thick ice that had grown in the river was used as a working platform (see Fig. 3).

ICE FORCE

The winter of 1989–90 was unusual because of the cold December, when the average temperature for the month was about 9°C below normal. On 16 January the ice thickness was measured to be 0.36–0.66 m (14–26 in.) near the pier. The ice covers over most rivers have a range of thicknesses because of nonuniform flow. The average temperature for the month of January, however, was above normal and the ice broke up and moved later in the month. Ice forces were not measured during this first ice run because the data acquisition system was not yet set up.

There was no ice at the bridge during the first week of February. However, a second ice sheet grew during the month, measuring 7.6–20 cm (3–8 in.) thick near the

Figure 3. Installation of the ice force panel in December 1989.

pier on 28 February. Our data acquisition system was installed on 1 March 1990. Cables from the load cell and pressure transducer were placed through a conduit that runs from the pier into the basement of a building on the east bank of the river. A schematic of this system is shown in Figure 4. The system is unmanned and automatically records ice force data whenever a preset threshold signal is detected from the load cell. These data, recorded on a tape recorder, are then processed at CRREL in Hanover.

Referring to Figure 2, we calculated the ice force F_{ice} by summing moments about the pin location so that

$$\Sigma M_{pin}: F_{ice} \times d = P \times D.$$

From this

$$F_{ice} = (P \times D)/d$$

where P = load cell signal (N)
D = fixed distance from the pin to the load cell (m)
d = variable distance from the pin to the water level as found from the pressure transducer signal (m).

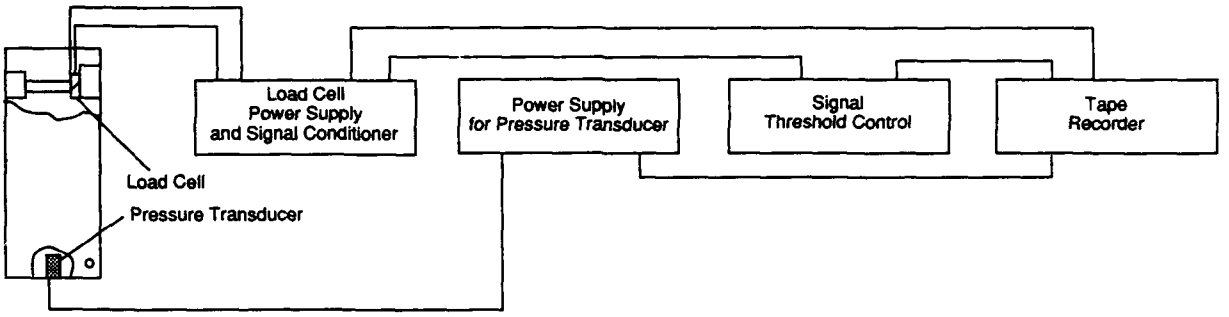


Figure 4. Data acquisition system.

This summation of moments does not include the mass of the panel itself because the load cell signal used was only that caused by ice interaction. Because we did not measure the ice thickness during the ice run on 16–17 March 1990, there may be some error incurred (0–5%) in the distance d, and thereby in our calculation of the ice force F_{ice}. Here, it is noted that d is the distance to the water level, and not to the center of the ice pressure.

Ice can interact with a bridge pier in several ways: impacting, crushing and splitting. In an impact situation, there may be very little damage to the floe, which may later rotate around the pier. Haynes et al. (1983) found that if the bridge pier has a nose inclined more than 20° from the vertical, the ice can ride up the nose and fail in bending. Another mode of ice failure is buckling, which can occur when the ice is thin.

On 15 March 1990, an ice floe measuring about 15 by 30 m and moving at a velocity of about 1.2 m/s (4 ft/s) hit the panel, as shown in Figure 5. The ice thickness was estimated to be about 15–20 cm (6–8 in.). On 16–17 March 1990, a major ice run took place. With most ice runs, the largest ice forces usually occur during the first 8 hours, while smaller ice floes can continue to strike the panel for a couple of days. Data from the tape confirm this pattern. A summary of the largest ice forces during this ice run is given in Table 1. Corresponding plots of the ice force versus time are shown in Figure 6. These were the largest forces measured in 1990, and they range from 94 to 355 kN (21,200 to 79,900 lb). There were many events for which the ice force was below 90 kN. For the ice force record shown in Figure 6a, the interaction event lasted about 2.5 seconds and is believed to represent crushing failure of the ice. A force record that has many oscillations (like that in Fig. 6a) without the force dropping to zero is often typical of an ice crushing event. The rapid increase in the ice force shown in Figure 6b indicates an impact followed by some crushing. For the event shown in Figure 6c, ice failure, believed to be by crushing, lasted about 2.3 seconds. A rapid increase and decrease

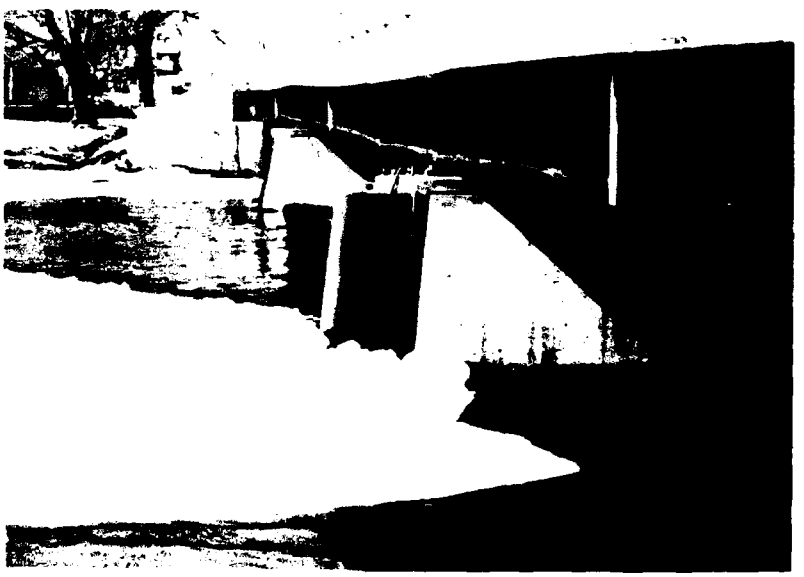
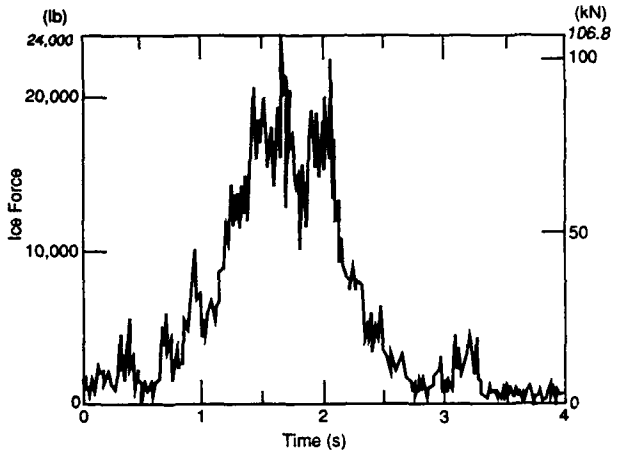
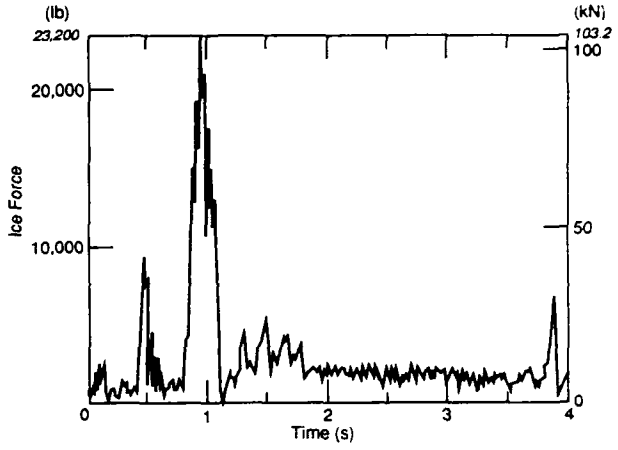


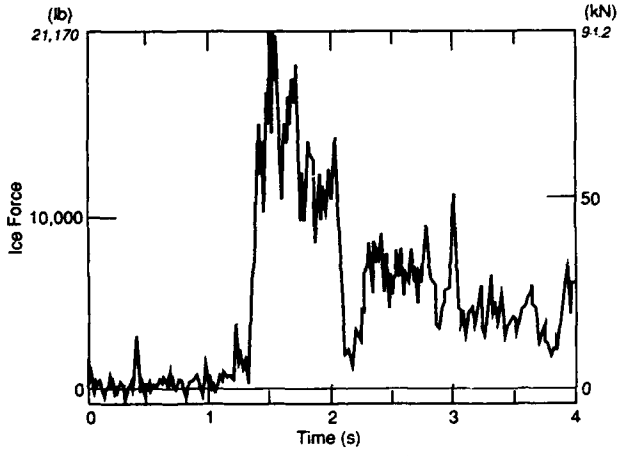
Figure 5. An ice floe impacting the panel on 15 March 1990.



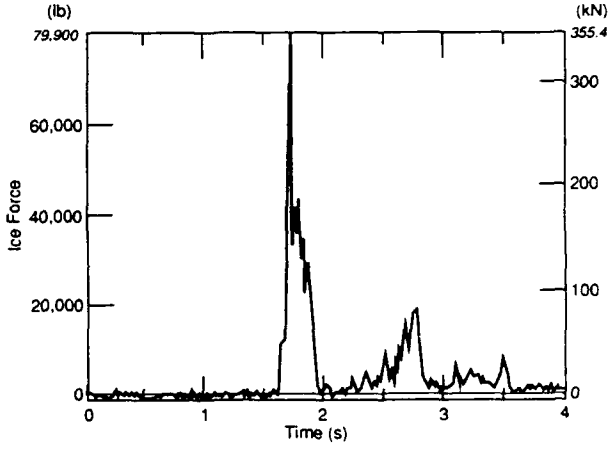
a. Event 1: This oscillation of the force signal indicates failure of ice by crushing.



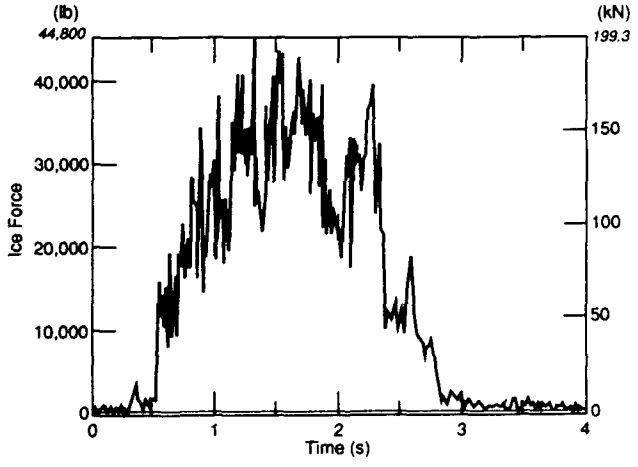
d. Event 4: An impact without much crushing.



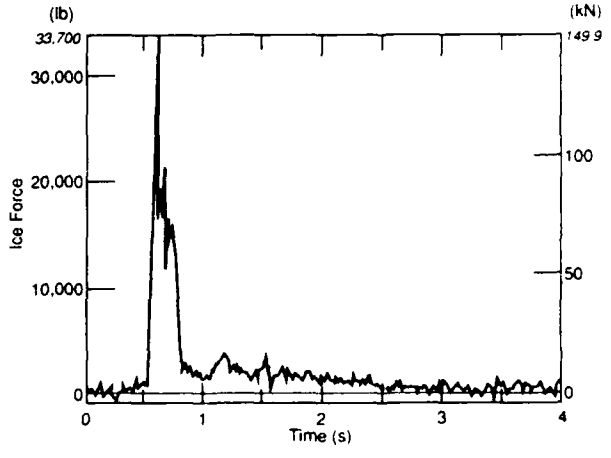
b. Event 2: An initial impact followed by some crushing.



e. Event 5: This ice impact produced the largest force measured in 1990, 355.4 kN.



c. Event 3: Ice failure by crushing.



f. Event 6: Ice impact without much crushing

Figure 6. Records of ice force versus time on 16–17 March 1990.

Table 1. Maximum ice forces recorded on 16–17 March 1990.

Event	Maximum force (kN)	Maximum force (lb)	Duration of event (s)	Type of ice–structure interaction
1 (Fig. 6a)	106.8	(24,000)	2.5	Crushing
2 (Fig. 6b)	94.2	(21,170)	0.82–2.2	Impact/crushing
3 (Fig. 6c)	199.3	(44,800)	2.3	Crushing
4 (Fig. 6d)	103.2	(23,200)	0.32	Impact with rotation or splitting
5 (Fig. 6e)	335.4	(79,900)	0.32	Impact with rotation or splitting
6 (Fig. 6f)	149.9	(33,700)	0.30	Impact with rotation or splitting

of ice force shown in Figure 6d indicates an impact and possible rotation of the ice floe without much crushing. This is usually the case with small, e.g., about 10- × 10-m, floes of strong, competent ice. The largest force measured was 355 kN (79,900 lb) as shown in Figure 6e. A similar type of event is indicated by the force record shown in Figure 6f.

DISCUSSION

The AASHTO (1983) design code gives a bridge designer a range of ice pressures from 700 to 2800 kPa (100 to 400 lb/in.^{2}) to choose from when designing a pier. The design engineer must also obtain as much site-specific information as possible, including the river bottom foundation material, ice thickness, ice strength, ice floe size, water velocities and river stage during breakup.

Piers for the new (1989) bridge over the St. Regis River in Hogansburg, New York, were built on bedrock. The river is about 90 m (300 ft) wide and has a 50-year discharge of 695 cm/s (21,000 ft^3/s) at this site. This is a typical medium-sized river in the northeastern United States. The design ice pressure was selected to be 2100 kPa (300 lb/in.^{2}) and the design ice thickness was 0.91 m (3 ft). The pier geometry includes a pointed upstream nose (included angle of 90°), inclined at an angle of 5.7° from the vertical. The piers are inclined laterally as well so that they are 1.53 m (5 ft) wide at the bottom and 0.91 m (3 ft) wide at the top. A maximum ice design load can be calculated by multiplying the ice pressure p by the ice thickness h and the pier width b, $F = phb$. Assuming a pier width of 1.22 m (4 ft), we calculate the design ice force to be 2.3 MN (518,400 lb).

In 1990, the maximum measured force on the ice force panel was 355 kN (79,900 lb), which is only 15% of the design load calculated above. However, this force was caused by an ice thickness estimated to be only 20 cm (8 in.), which is 22% of the design ice thickness of 0.91 m.

One question to address in the design of a panel for measuring ice forces is the natural frequencies of the panel itself. These frequencies should be much higher than the frequencies associated with ice–structure interaction so as to avoid resonance. If the panel is relatively flexible and has natural frequencies in the same range as the ice–structure interaction frequencies, it is almost impossible to determine whether the signals are caused by ice forces or structural response. Frequencies associated with ice crushing have been studied in the laboratory by Sodhi and Morris (1984) and Sodhi and Nakazawa (1990). They found these frequencies to depend on ice velocity, ice thickness, structure width and stiffness. The natural frequencies of the panel installed at Hogansburg were determined by striking the panel and analyzing the load cell signal in the frequency domain. These frequencies were found to be 116 and 173 Hz, which are sufficiently above the ice–panel interaction frequencies to avoid resonance.

FUTURE STUDY

CRREL plans to measure ice forces at this site for several more years. It would be valuable to know the ice thickness and the ice velocity. CRREL is investigating techniques, such as sonar, for measuring the ice thickness and time-lapse photography or radar for measuring ice velocity. When personnel happen to be at the site during an ice run, observations of ice velocity will be made directly.

It is expected that during this multi-year program there will be a good compilation of data to aid designers of bridge piers. The data from this study will also enable AASHTO to consider revision of the AASHTO (1983) code.

CONCLUSIONS

The ice forces measured in 1990 were from the ice movement that occurred in March. The estimated ice thicknesses were in the range of 5–20 cm (2–8 in.), and

the maximum ice force measured was 355 kN (79,900 lb). It is expected that ice force data useful to the New York State Department of Transportation, CRREL, and the engineering community at large will be obtained during the next several years. The data collected can be used to make statistical analyses about the probability of a given magnitude of force on a pier located in a medium sized river in the northeastern United States.

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13. ABSTRACT (*Maximum 200 words*)

An ice force panel was installed on the upstream nose of a pier of the new (1989) bridge over the St. Regis River at Hogansburg, New York. This panel is a simply supported beam, pinned at the bottom, and has a load cell for the reaction at the top. Ice forces measured with this panel during the 16 March 1990 ice run are presented. Ice failed against the panel by impact, by crushing and possibly by splitting of the floes.

14. SUBJECT TERMS

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Design code
Ice
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River
River ice
St. Regis River

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